

AN INTELLIGENT CHEMICAL RECOMMENDATION
AND APPLICATOR CONTROL SYSTEM
FOR SITE-SPECIFIC CROP MANAGEMENT

by

MARTIN LEROYCE EIS

B.S., Kansas State University, 1986

A THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

ELECTRICAL AND COMPUTER ENGINEERING

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1989

Approved by:

Eddie R. Fowler
Major Professor

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ACKNOWLEDGMENTS

I am grateful to Dr. Dave Kissel for all the time he spent answering questions and providing needed information for this project. I thank Dr. Steve Thein and Dr. John Havolin for their help and assistance in taking their classes. I would also like to thank Dr. Larry Unruh for his help with the KSU Soil Testing Laboratory's procedures. I thank Keith Hefty for his instruction on the various software and hardware used for this project. Finally, I thank the members of my graduate committee, Dr. Mark Schrock, Dr. Steve Young, Dr. Donald Lenhert, and my major professor, Dr. Eddie Fowler.

1. INTRODUCTION

1.1 Motivation

Current methods of crop production are done on a field by field basis. Each field may vary in factors that affect crop production, such as nutrient levels, soil types, moisture content, etc. For optimum farm management, these spatial variability factors should be taken into account on a site by site basis when determining inputs to the field. Site-specific crop management customizes inputs such as fertilizer, herbicides, and pesticides to optimize yields, minimize costs, and reduce environmental impacts. Systems are being developed to tailor chemical application to each specific site in a field. Terms to describe this variable rate application strategy include: site-specific crop management; prescription farming; farming by the grid or foot; and, farming soils, not fields. This paper will use site-specific crop management. Studies from Montana State University show that customized fertilizer application for crop production potential at each specific site in a field will result in an average savings of approximately \$12.00 per hectare [1,2,3,4]. Site-specific crop management will help to control groundwater contamination due to leaching caused by excess application of fertilizer, herbicides, and pesticides.

1.2 Project Overview

An intelligent general purpose chemical recommendation and applicator control system structure that allows for site specific application of any chemical used on production land is the topic of the research presented here. This intelligent general purpose system is a knowledge based system that is able to both recommend the amount of chemical to be applied to production land and control the application of the chemical. The general purpose structure can be adapted to recommend and apply any appropriate chemical for use in farm management, such as fertilizers, pesticides, or herbicides. The knowledge incorporated in the structure depends on the heuristics and factors involved for any particular field. This system is used as an aide to the producer in site-specific crop management. The applicator operator is able to manually override this automated control system and continue application at any desired rate set by the operator.

To demonstrate the capabilities of the general purpose system structure, an intelligent nitrogen rate recommendation and applicator control system is created. This system is developed as both a feasibility study and a proof of concept system. Nitrogen is chosen because it is

a primary macronutrient in crop production. Also, measurement techniques are available for determining the nitrogen levels in the soil. Two spatial variability factors are included in this system, namely yield rate and soil type. The knowledge used in this system is based on the recommendation of the Kansas State University (KSU) Soil Testing Laboratory (STL) and the KSU Agronomy Department [5,6,7,8]. Since this system is implemented by integrating Texas Instrument's Personal Consultant Plus, Images, and Online development software, it demonstrates the feasibility and capabilities of such an integration for this application.

1.3 Thesis Overview

This thesis will discuss the development, implementation, and performance of the intelligent nitrogen recommendation and applicator control system. This knowledge base is implemented using frame based reasoning techniques available with Texas Instrument's Personal Consultant Plus development tools [9,10,11,12,13,14]. Also, this thesis will review how two other techniques, namely Truth Maintenance Systems and Neural Networks, can be used to implement or enhance portions of the knowledge based system.

2. DEVELOPMENT

2.1 Spatial Variability

Yield variance of a crop within a field can be caused by a wide variety of factors [7,8]. These factors include: soil nutrient contents; soil type; soil conditions; tillage practices; cropping sequences; weather; crop variety; disease; insects; and, so forth. All have affects on yield variance as well as each other. The relationships between these factors is a study within itself and will not be explained in this thesis. In order to manage yield variability effectively, as many as possible of the above listed factors, as well as economic considerations, should be managed. The management of these individual factors with respect to crop production requires complex and abstract relationships. Thus, management of these factors is an excellent candidate for an artificial intelligent approach. Nitrogen, as an example, is spatially dependent on the amount of organic matter in the soil, the amount and type of crop residue, plant uptake of nitrogen, microbial activity, leaching, and so forth. In this thesis, only two spatial factors, yield rate and soil type, are considered in determining the nitrogen fertilizer requirements needed to manage the nitrogen levels in the soil. The yield rate is related to

nitrogen levels in the soil. The yield rate is related to the plant uptake and the soil type is related to leaching and organic matter content. The total affect of these two factors is not fully known, but is used in the intelligent nitrogen recommendation and applicator control system as a proof of concept for the intelligent recommendation and applicator control system structure. When the relationships between the spatial variability factors are determined, they can be added to each intelligent chemical recommendation and applicator control system to help in site-specific crop management.

2.2 Yield Mapping System

The mapping of crop yields as a function of location is necessary for site-specific crop management. The KSU Agriculture Engineering Department has developed a system for mapping crop yields [15]. The system block diagram is shown in Figure 2-1. This system contains an auger based grain flow sensor which uses a pivoted auger as a continuous mass flow sensor. Data from the pivoted auger is sampled and processed using a Zenith Data System Z-158 microcomputer, equipped with a Tecmar LabMaster data acquisition system, installed in the cab of a combine. This processed data can be converted into a yield map of

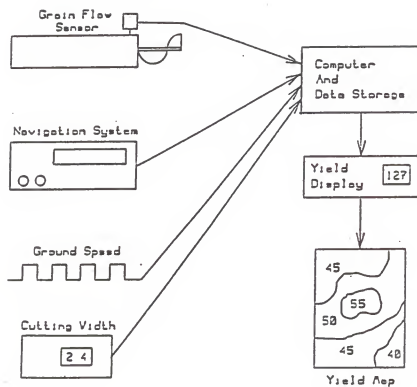


Figure 2-1: Yield Mapping System Block Diagram [16]

acquisition system were done on wheat and corn at different moisture contents. Operational field tests were conducted on wheat and grain sorghum. Both stationary and operational tests indicated that the grain flow sensor provides accurate measurements for determining yield variations in the field and for creating a yield map of the field. Presently, no algorithms have been developed to construct a yield map from the sensor data obtained from the field. However, the development of such algorithms is a feasible task.

2.3 Soil Testing Laboratory Recommendations

The knowledge used for this report is based on the soil test interpretations and fertilizer recommendations developed at the Soil Testing Laboratory (STL) of Kansas State University (KSU) [5]. ("Fertilizer recommendations" refers to both type and application rate.) A soil test report form is shown in Figure 2-2. Several soil tests are available from the STL. These tests measure the following soil conditions: soil pH; available phosphorus; exchangeable potassium; available profile nitrogen; available zinc; available iron; and, organic matter content. Once these conditions are determined by performing tests on a soil sample from a field, certain



SOIL TESTING LABORATORY
 THROCKMORTON HALL
 KANSAS STATE UNIVERSITY
 MANHATTAN, KANSAS 66506
 PHONE 913 532-5776

DATE RECEIVED:
 DATE REPORTED:
 COUNTY:
 LAB NUMBERS:
 TOTAL COST:

SUBMITTED BY: _____

FOR: _____

TEST	ROUTINE				ADDITIONAL				SPECIAL
FIELD IDENTIFICATION	SOIL PH	LIIME ECC #1A	PHOSPHORUS LBS/A	POTASSIUM LBS/A	ORGANIC MATTER %	OTPA PPM ZN	SURFACE/SUBSOIL PPM FE	PROFILE N -- -- PPM NO3-N -- --	

FIELD INFORMATION					RECOMMENDED FERTILIZER LBS/A						
FIELD IDENTIFICATION	PREVIOUS CROP	YIELD	PREVIOUS FERTILIZER N	P2O5 K2O OTHER	INTENDED CROP	YIELD GOAL	LIIME ECC #1A	NITROGEN N	PHOSPHATE P2O5	POTASSIUM K2O	ZINC ZN

COMMENTS: _____

RECOMMENDATIONS MADE BY: _____

Figure 2-2: Soil Test Report

interpretations and recommendations can be made for that field. Since no federal or state standard soil testing and reporting procedures exist, the interpretations and recommendations, based on the KSU STL's soil testing and reporting procedures, can not be extrapolated to another laboratory's soil test results without knowing the other soil testing and reporting procedures and methods. The interpretations based on the soil tests determine if a recommendation for corrective or preventive action is required. Presently, the STL makes fertilizer recommendations based on a set of equations contained in the STL fertilizer recommendation software [6]. These equations are dependent on the following information: the intended crop and yield goal; irrigation; the amount of nutrient presently in the soil; the soil texture, or type; the current tillage practices; the location within the state; and, the previous crop and yield average. Since nitrogen is the only nutrient being considered for application in this report, its recommendation rate equation is the only one discussed. The nitrogen rate recommendation equation used by the STL is:

$$\text{NREC} = (\text{NX1} * \text{YG} - 7.5 * \text{NPROF}) * \text{TEXTURE} - \text{LEGUME} - \text{FALLOW} - \text{MANURE}$$

where,

NREC - Recommended nitrogen application rate
(lbs/Acre)

NX1 - A coefficient dependent on the crop and irrigation

YG - Yield goal

NPROF - Nitrogen content in the soil profile (ppm)

TEXTURE - A coefficient dependent on the soil type

LEGUME - A deduction factor for the previous crop being a legume

FALLOW - A deduction factor of 20 lbs/Acre for having fallowed the ground

MANURE - A deduction factor of the nitrogen content of any manure applied to the field

Both YG and NPROF have default values dependent on the intended crop, irrigation, and location within the state. The values for each of the first five factors, as related to their dependencies, are shown in Tables 2-1 through 2-3. Presently, the STL's fertilizer recommendation software does not adjust for the soil type. The recommendation software rounds the nitrogen rate to the nearest tens digit. A round off error occurs in this process requiring an adjustment factor in the recommended nitrogen rate as explained in Appendix E. This adjusted nitrogen rate is placed in the soil test report shown in Figure 2-2.

Crop	Irr	Crop Type	NX1	NPROF Default (ppm)	Default Yield Goals						Units per acre
					Eastern		Central		Western		
					Lo	Hi	Lo	Hi	Lo	Hi	
Alfalfa	No	Legume	0.00	0	3	6	2	5	2	4	Ton
Alfalfa	Yes	Legume	0.00	0	6	10	6	10	6	10	Ton
Corn	No	Row	1.30	4	80	160	50	80	0	0	Bu.
Corn	Yes	Row	1.35	5	125	200	125	200	125	200	Bu.
Soybeans	No	Legume	0.00	0	30	70	25	40	0	0	Bu.
Soybeans	Yes	Legume	0.00	0	40	70	40	70	40	70	Bu.
Sorghum	No	Row	1.25	4	80	140	60	100	40	80	Bu.
Sorghum	Yes	Row	1.35	5	100	160	100	160	100	160	Bu.
Wheat	No	Grain	1.75	3	40	70	35	70	25	45	Bu.
Wheat	Yes	Grain	1.75	3	50	100	50	100	50	100	Bu.

Table 2-1: Nitrogen rate recommendation equation coefficients NX1, YG default, and NPROF default

	Sandy soils	Non-sandy soils
TEXTURE	1.1	1.0

Table 2-2: Nitrogen rate recommendation equation coefficient TEXTURE

Crop Type	LEGUME (lbs/A)
Legume	alfalfa - 150 soybeans - 30
Grass	0
Grain	0
Row	0

Table 2-3: Nitrogen rate recommendation equation coefficient LEGUME

2.4 The Knowledge Based System Recommendations

A knowledge based system was used to combine spatial variability factors with the nitrogen rate recommendation equation. A knowledge based system is a computer system that solves complex, real world problems that require significant human knowledge for their solution. A block diagram of a knowledge based system is shown in Figure 2-3. The knowledge base is the facts and rules that represent the problem. The inference engine is the implementation of techniques used to solve the problem. In this system, the knowledge base consists of the recommendation equation, the spatial variability factors, and the relationships between the factors. The inference engine uses frames and rules to determine the nitrogen variability of the field. The nitrogen variability is represented by a nitrogen rate recommendation map. To maintain compatibility between this system and the STL's recommendation software, the same nitrogen rate recommendation equation is used. However, only corn and wheat are implemented on this system, so the legume factor is not included. Also, no deductions are made for manure or fallowed ground. The nitrogen in the soil profile must be determined prior to consulting the system. This gives a base value for the recommendation equation.

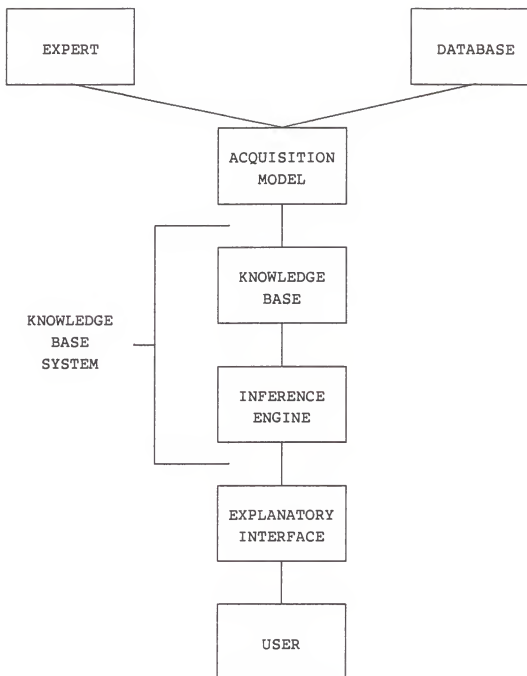


Figure 2-3: Knowledge Base System

The soil texture factor is included as a spatial variability factor in the equation. The yield rate is the only other spatial variability factor included in this system. There is indication of a small negative correlation between nitrogen content remaining in the soil and the wheat yields produced [8], though more studies are needed to examine this relationship. This implies that the higher the yield, the more nitrogen removed, and the lower the nitrogen content remaining in the soil. Also, the lower the yield, the less nitrogen removed, and the higher the nitrogen content remaining in the soil. This relationship holds true as long as the nitrogen levels are not deficient, in which case the lower yields indicate the need for increased amounts of nitrogen. The amount of nitrogen removed is approximated using the yield produced [7]. For wheat, 1.75 lbs/Acre of nitrogen are removed for every bushel of wheat produced. For corn, 2.55 lbs/Acre of nitrogen are removed for every bushel of corn produced. Knowing this relationship, the recommended nitrogen rate is adjusted according to the variations in the yield rate at a specific site from the average yield of the field.

3. PC Plus, PC Images, and PC Online - IMPLEMENTATION TOPICS

3.1 The Personal Consultant System

The Nitrogen Recommendation and Application Control System (NAPP) was developed using Texas Instrument's Personal Consultant Plus (PC Plus) [9,10]. PC Plus is a highly functional tool for developing expert system applications. PC Plus offers a sophisticated frame structure, techniques for imposing rule-order strategies, and the ability to extend and customize the consultation environment. PC Plus is suited for development of complex expert systems on personal computers, as well as for rapidly creating initial concept or prototype systems. Two additional development tools are used to enhance the capabilities of PC Plus. These tools are Personal Consultant Images (PC Images) [11] and Personal Consultant Online (PC Online) [12]. PC Images allows incorporation of graphic images to enhance visual interaction with the user. PC Online allows interaction with process control requiring little or no operator intervention. Because of these capabilities and the commercial availability of PC Plus, it is the choice for this implementation.

The development power of PC Plus gives it many features, but also some inherent limitations. PC Plus features

include: natural language interfaces; built-in explanatory functions; ability to use LISP and external languages, like C; and, an interactive development environment. Some of its limitations include: its graphic capabilities; knowledge base modifications; and, processing speed.

PC Plus uses three basic structures to control and organize knowledge within a knowledge base. These structures are frames, parameters, and rules. Frames are used to organize the knowledge base into related groups of information. The information is represented within a frame using parameters and rules.

Every knowledge base must have at least one frame, called a root frame, and may contain additional frames, called subframes. Whenever the knowledge base is consulted, the root frame is instantiated, or created. A subframe is instantiated only if the inferencing requires a conclusion from that frame to solve the problem. Subframes can be instantiated as many times as needed to reach the solution. This is done by using the PROMPT1ST, PROMPT2ND, and PROMPTEVER frame properties. Subframes inherit all of the knowledge possessed by its parent frame.

Parameters are slots within the frame in which facts or information may be stored. PC Plus provides several types

of parameters which may be used. These types vary according to the value the parameter is permitted to contain. Values for parameters may be acquired from the user using the parameter's PROMPT property or assigned by rules in the knowledge base.

Rules are used to arrive at the solution to the problem by providing relationships between parameters. Rules are comprised of two sets of clauses, namely IF and THEN. When the IF clauses, or premises, are met, the THEN clauses, or conclusions are activated.

The inferencing strategy of PC Plus is a goal driven or backward chaining process. For this reason, every knowledge base must have at least one goal. For every goal in a frame, PC Plus searches the conclusions of the frame's rules for that goal. When a rule is found which assigns a value to the goal in its conclusion, the rule is tried. If the conditions in the premises are met, PC Plus applies all the conclusions of the rule, satisfying the goal. This process continues until all goals within the frame are satisfied. If all rules are exhausted and a goal not satisfied, PC Plus informs the user that it was unable to reach any conclusion for that goal.

NAPP requires special operations that no PC Plus function

can perform. In order to perform these operations, the functions are written in LISP and C.

LISP functions may be created as either user-defined functions or user-written functions using Personal Consultant Scheme (PC Scheme) [13,14]. User-defined functions are created within the PC Plus development environment and require a strict formatting style. User-written functions are created outside of the PC Plus environment and allow for a relaxed formatting style. These functions must be placed in either the kb-name.CST file or the CUSTOM.PC file. User-written functions are used for implementing NAPP and are placed in NAP1.CST (See Appendix B). Both user-defined and user-written functions can be called using (E (function-name argument-list)) within PC Plus.

Likewise, C functions are written in two different ways, each requiring a different calling procedure. The first way is to create a C function which may be executed independently of PC Plus. The program must accept all its arguments from the command line. The executable file is then called using (DOS-CALL "filename" "argument-list"). DOS-CALL halts PC Plus, loads and executes the external program, and then returns to PC Plus. This process is

very time consuming and should be avoided in real time applications. The second way is to use PC Scheme's external language interface (XLI) capabilities. When using XLI, the function must include specific programming structures to support the interactions with PC Scheme. This is because the program runs simultaneously with PC Plus. (See PC Scheme User's Guide for details on the XLI process. [13]) PC Scheme provides an example Microsoft C XLI program which was modified for use with NAPP (See Appendix C).

Several data files are used with NAPP (See Appendix D). PC Plus provides several functions which are used for data retrieval and storage.

The function IMPORT allows data to be retrieved from an external source. Its format is IMPORT '(import-adapter), where the import-adapter function assembles the desired data into a form that IMPORT uses to assign the data. The form required is a list containing parameter/value sets, i.e., ((parameter-1 value-1 ... value-X) ... (parameter-Y value-1 ... value-Z)). One possible import-adapter provided by PC Plus is DOS-FILE-IN. DOS-FILE-IN retrieves data from an ASCII text file and combines the data read in with the parameters in its argument list. The data must be written in comma separated variable (CSV) format.

The function EXPORT allows data to be stored to an external location. EXPORT's format is EXPORT '(export-adapter (parameter-list) export-adapter-arguments), where the export adapter exports the values of the parameters in the parameter-list to an external location in the manner specified by the export-adapter-arguments. PC Plus provides DOS-FILE-OUT as an export-adapter. DOS-FILE-OUT writes data to an ASCII text file. It either appends the data to the end of the file or creates a file with the new data. DOS-FILE-OUT allows for data to be written in CSV format if desired. Both IMPORT and EXPORT are used in NAPP with the data files in Appendix D.

PC Images is an additional tool used with PC Plus. It allows active images and background pictures to be grouped together on one screen. Active images are images that are associated with parameters. Active images may be either input or output images. Input images replace the PROMPT property of the parameter. Output images are used to display the value of the parameter. PC Images display several types of active images. These images are placed onto a background picture created with a third party graphics editor. The active images and the background picture are made into a cluster, which appears as one

screen. Whenever any parameter is needed within the cluster, the entire cluster is displayed on the screen. This allows for several parameters to be displayed at the same time, reducing the number of screens required. Each image in the knowledge base is stored in a graphics file with the extension .GRI.

PC Online is another tool used with PC Plus. With PC Online, knowledge base applications, in which the system state changes with time, are implemented in an automated fashion. PC Online enhances PC Plus' frame and user interface management. Also, it adds the ability to manage memory, time, and knowledge base data.

In implementing NAPP, the frame, user interface, and memory management features are used. Frame instantiation is controlled automatically using the frame's PREMISE property, the IMPORT function, and the knowledge contained in the knowledge base. An example of this is batch processing, where a frame is instantiated for each line in a data file. The PREMISE property is used to control the frames instantiation. Using IMPORT with DOS-FILE-IN as the premise to the frame, the frame is automatically instantiated for each line in the data file. When the end of the file is reached, the premise fails and no more frames are instantiated. User interaction is controlled

with new options available with PC Online. The NO-RETURN-KEY option is used in the NAPP knowledge base. This option allows for goals to be displayed without having to press the RETURN key. Also, an alarm feature has been added with PC Online. The ALARM function sounds a warning, displays a message, and/or waits for the user to respond to the alarm. Memory management is used to remove frames that are no longer required in the knowledge base. This is done by using the DELETE-DYN-FRAME function. Thus, an unlimited number of frames can be created without running out of memory. Using the above features both batch processing and process control are implemented in NAPP.

3.2 The Intelligent Nitrogen Recommendation and Applicator Control System

The Nitrogen Recommendation and Application Control System (See Appendix A) consists of an input subsystem, a recommendation subsystem, and a control subsystem. The input subsystem acquires data from the user, the yield mapping system, and external graphic devices. It combines this data into one file containing both general field data and site specific data. The recommendation subsystem uses the file created by the input subsystem and other

information provided by the user to create a nitrogen rate recommendation map for the field. Also, it calculates the average nitrogen rate recommendation for the field. The control subsystem uses the applicator location and the nitrogen rate recommendation map to obtain the recommended nitrogen rate to be applied at each specific site. Once the rate is determined, the valve settings on the applicator are set by an automated control system using the following input data: the nitrogen rate; the type of nitrogen fertilizer being applied; the type of applicator; and, the ground speed of the applicator vehicle. Presently, development of the input system has not been initiated, the recommendation system is operational, and the control system is under development. It is assumed that only reasonable entries are entered as inputs to this system and therefore the system does not check for unreasonable input data. However, a set of upper and lower limit "alarms" could be added for unreasonable entries.

The structure that implements the NAPP system on PC Plus is shown in Figure 3-1. The first two frames, NAPP and FUNCTION, are used for administrative (supervisory) purposes. These frames control the operation of the NAPP system and hold data common to all three subsystems. NAPP

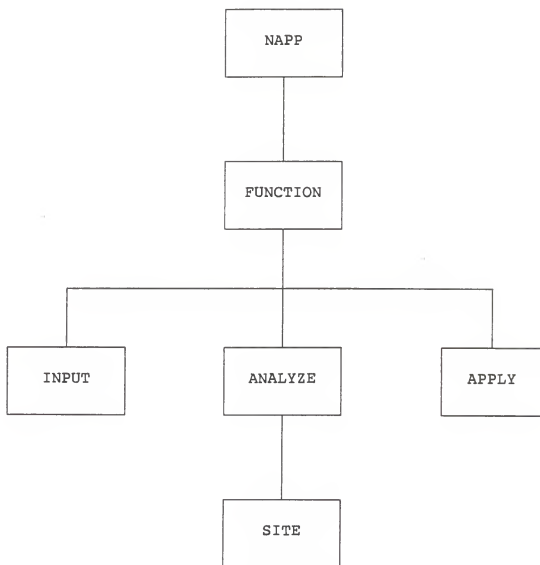


Figure 3-1: NAPP Frame Structure

is the root frame and is instantiated when the system is started. The NAPP frame introduces the NAPP system and instantiates its child frame, FUNCTION. This is accomplished by using a single goal and a single rule. The rule's premise defaults to "true" causing the goal to be satisfied and the creation of the frame FUNCTION. FUNCTION allows the user to execute one of the following operations: input; analyze; apply; or, exit. If input is chosen, the INPUT frame is instantiated, executing the input subsystem. If analyze is chosen, the ANALYZE frame is instantiated, executing the recommendation subsystem. If apply is chosen, the APPLY frame is instantiated, executing the control subsystem. If exit is chosen, the FUNCTION frame is closed, ending the consultation. The execution of the subsystems are discussed in the following paragraphs.

3.3 The Input Subsystem

Presently, the input subsystem consists of the empty frame INPUT. The input subsystem creates a file to be used in the recommendation subsystem containing a line indentifying the field and a map of the field. The line indentifying the field contains the following data: the profile nitrogen content from the soil lab test report;

the previous crop and average yield; and, the county in which the field is located. The field map consists of the yield map and the soil map of the field. The field map is in vector format and contains entries in the following format: the site's relative latitude and longitude; the previous crop's yield at that site; and, the soil type at that site.

The field map is divided into grids, called sites. The input maps must be contour maps to allow use of any size grids on the field map. To convert input maps sampled in a grid fashion into contour maps, a minimum input map grid size is required. To meet this required grid size minimum, the following four assumptions are made. The first is that the minimum input map grid size is primarily a function of the position accuracy of the navigation system. The second is that the required position accuracy is primarily a function of the implement size. The third is that in the NAPP system, the navigation system has a position accuracy of less than one half the implement width. With this accuracy, the fourth is that the grid size is chosen to be no less than twice the width of the implement. Therefore, all the contour widths are equal to the widest implement used to collect input data. Finally, the field map grid size can be no less than the width of

the input map contours.

The portion of the input subsystem that creates the field map is called a Geographic Information System (GIS) [17]. A GIS is a "map database" which overlays geographically referenced, or spatial, data on a base map. This spatial data can be manipulated and managed by the GIS. Since the field data is in a vector, or digitized, format, the GIS uses the same format. Thus, both the yield map and the soil map are in the digitized format. The yield map is already stored digitally by the yield mapping system [15] and is converted to a proper format. The soil map is digitized manually using a digitizer. These two maps are then combined into a map of the field which is used by the recommendation subsystem.

3.4 The Recommendation Subsystem

The recommendation subsystem consists of two frames, ANALYZE and SITE. ANALYZE is used to hold data that is constant within the field. SITE is used to hold data for each specific site, to calculate the recommended nitrogen rate for each specific site, and to develop a nitrogen rate recommendation map for the field. Data that is constant throughout a field includes: the intended crop and yield goal; whether the field is irrigated; the

location of the field within the state; the previous crop and average yield; the amount of nitrogen in the soil profile; and, the nitrogen rate recommendation equation coefficients. The site specific data includes: the relative latitude and longitude of the site; the soil type; and, the previous crop yield at the site. ANALYZE requests the filename that contains the field data to be used in the analysis and reads in the general field data using the PC Plus IMPORT and DOS-FILE-IN functions. Next ANALYZE prompts the user for the intended crop, yield goal, and if the field is to be irrigated. Both the intended crop and the yield goal are prompted with PC Images. The intended crop uses a "select region" image on a background picture to receive its value. The yield goal screen displays a map of Kansas showing the average yields of each region of Kansas and a prompt for the yield goal. The average yields and the yield goal are "digital display panel" images. The yield goal image is preset to the average yield of the region in which the field is located. The user can adjust the value of the yield goal by using the arrow keys. Once this information is entered, the appropriate nitrogen rate recommendation equation coefficients are read in from the NAP.DAT file (See Appendix D) using IMPORT and the user-written PC Scheme

function, NEQDATA, (See Appendix B) and a SITE frame is instantiated. A SITE frame is generated for each specific site within the field. Each time a frame is being instantiated, a line from the field data file is read in using the frame's PREMISE property. This line contains the parameters specific to that site. The SITE frame then calculates the recommended nitrogen rate for the specific site and adds it to the nitrogen rate recommendation map by appending it to the nitrogen rate recommendation file specified by the user. Also, SITE keeps a running total of the nitrogen rates and the number of sites visited. Then the frame is deleted to save memory, and a new frame is instantiated with new values. This process continues until the end of the field data file is reached, at which time PC Plus returns to the ANALYZE frame. Then, the ANALYZE frame calculates the average nitrogen rate from the totals kept during the site calculations. The user then considers another field or returns back to the FUNCTION frame and chooses another operation.

3.5 The Control Subsystem

The control subsystem consists of one frame called APPLY. This frame determines the location of the applicator, searches the nitrogen rate recommendation map for that

site, and outputs and displays the recommended nitrogen rate for the specific site.

The applicator vehicle movement and detection is being simulated by using a file containing a list of specific sites within the field. An APPLY frame is instantiated for each specific site in the list. Each time an APPLY frame is created, one site is read from the file using the frame's PREMISE condition and PC Plus functions, IMPORT and DOS-FILE-IN. When no more sites exist in the list, PC Plus returns to the FUNCTION frame where another operation is chosen. Once each frame's task is completed, it is deleted to save memory and clear space for another APPLY frame. In an actual implementation the applicator's location is detected using a navigational system. In developing the yield mapping system, several navigational systems were studied [15,18]. Among the more promising of these are the LORAN navigation system and the Global Positioning System (GPS). In the near future, both systems should provide the position accuracy needed for the NAPP system.

The LORAN (Long-Range Aid to Navigation) system is a ground based navigation system developed during World War II. Though originally used for navigation by ocean vessels and bombers in the European Theater, by the end of

the war coverage had extended over much of the Pacific Ocean. LORAN consists of a series of fixed transmitters which emit pulses in a precisely timed sequence. The time delays between the receipt of the signals by the receiver are used to calculate the receiver's current position. LORAN has a position accuracy of 50 to 100 meters. However, there is a mid-continent gap, where the LORAN system currently does provide coverage. This gap is approximately 500 kilometers wide running north and south through the high plains [15].

The Navstar Global Positioning System (GPS) being developed by the Department of Defense is able to determine the position of land, sea or airborne crafts in two or three dimensions [15,19]. GPS is a space based navigational system consisting of 18 satellites, four of which are available at any given time and location. Currently, only nine of the GPS satellites are in place. GPS uses the same basic principles of signal time differences developed for LORAN. When GPS is available for civilian applications, an accuracy of about 100 meters will be available with a single receiver. In order to obtain greater accuracy, an additional reference receiver located at a known fixed location is required. However, depending on the geographical topology, the transmitter

power, and the receiver sensitivity, the additional reference receiver can service several counties simultaneously.

PC Plus uses the user-written PC Scheme function, GETNRATE, (See Appendix B) to search the nitrogen rate recommendation map specified by the user and returns the recommended nitrogen rate of the current site to PC Plus via the IMPORT function. GETNRATE requires three arguments, the site's relative latitude and longitude, and the nitrogen rate recommendation map's filename. If the current site is not contained in the map, GETNRATE returns a rate of zero. This prevents the application of nitrogen outside the boundary of the field. The PC Scheme function NOUTPUT sends the nitrogen rate to an external controller via an output port. The external language interface feature of PC Scheme is used to send out this rate, since it allows the displayed images to remain on the screen within PC Plus. The DOS-CALL function clears the screen each time it is invoked and redraws the display after execution is complete. A Sample Microsoft C XLI program provided with PC Scheme has been modified to output the nitrogen rate in Binary Coded Decimal to the printer port, LPT2, located at 0x0278 (See Appendix C). This port is chosen because of its availability and the lack of a more

general parallel I/O interface card. The executable C program is called from NOUTPUT using the PC Scheme function, XCALL. Presently, the nitrogen rate is sent to a display to demonstrate PC Plus external output capabilities. The controller for the applicator is not developed at this time. But, one of its capabilities must be the ability to allow for manual override from the operator at any time. This manual override should allow for the operator to enter a new nitrogen rate and continue application at that rate.

The nitrogen rate received by PC Plus and the site's relative latitude and longitude are displayed for the operator via PC Images. The latitude and longitude are presented using active "digital display panel" images. The nitrogen is presented using an active "vertical bar graph" image. This display remains on the screen during the entire control sequence. The values of these active images change as the applicator vehicle moves across the field showing its present position and rate. When a nitrogen rate of zero is encountered, the control system sounds an alarm and displays a message indicating no nitrogen is being applied.

4. Performance

4.1 Capabilities

The Intelligent Nitrogen Recommendation and Applicator Control System provides nitrogen recommendations for two crops, corn and wheat. Also, NAPP provides for automated control of the applicator output rate with manual intervention included. NAPP requires the use of two files which presently must be created by the user (See Appendix D). These files are the field data file and the applicator location file. The field data file contains the combined previous yield rate map and the soil map of the field. The applicator location file, called SITE.DAT, contains the sites to be visited by the applicator. The field data file will eventually be created by the input subsystem. The applicator location file will eventually be replaced by the sampling of the applicator location directly with a navigational system. NAPP contains several image displays to help convey information to the user. All other information is obtained and displayed with the existing PC Plus user interface techniques. The recommended nitrogen rates are sensitive to unit changes in the previous yield rate. The NAPP system does not account for nitrogen deficiencies within the field. These areas must be covered using manual intervention of the

control system. The system does not account for overlaps in application, but does provide for edge detection of the field. If the applicator goes outside the field boundary, a nitrogen rate of zero is applied.

NAPP is a simple-minded system in the sense that it only uses two of the spatial variability factors in the recommendation system. Also, these factors are only used as arguments in an algorithmic equation and not in any heuristic functions. In order for NAPP to be effective in site-specific crop management, many other factors must be included in the algorithmic equation and in added heuristic functions.

4.2 Comparison of Results

The recommended nitrogen rates for various conditions determined by both the KSU STL and the Intelligent Nitrogen Recommendation and Applicator Control System are shown in Table 4-1. The only input to the nitrogen rate recommendation equation not shown in Table 4-1 is the nitrogen content of the soil profile, which is set equal to 4 ppm. The STL recommendations are independent of the variations in soil type. Also, since only corn and wheat are considered, the previous crop and yield do not effect

Previous Crop	Irrigation	Area of State	Intended Crop	Yield Goal bu/A	Recommended N		Error lbs/A
					Soil Lab lbs/A	NAPP lbs/A	
Wheat	No	West	Corn	65	60	59	-1
Wheat	Yes	West	Corn	163	190	194	4
Wheat	No	West	Wheat	35	40	35	-5
Wheat	Yes	West	Wheat	75	110	105	-5
Corn	No	West	Corn	65	60	59	-1
Corn	Yes	West	Corn	163	190	194	4
Corn	No	West	Wheat	35	40	35	-5
Corn	Yes	West	Wheat	75	110	105	-5
Wheat	No	Cent	Corn	65	60	59	-1
Wheat	Yes	Cent	Corn	163	190	194	4
Wheat	No	Cent	Wheat	53	70	67	-3
Wheat	Yes	Cent	Wheat	75	110	105	-5
Corn	No	Cent	Corn	65	60	59	-1
Corn	Yes	Cent	Corn	163	190	194	4
Corn	No	Cent	Wheat	53	70	67	-3
Corn	Yes	Cent	Wheat	75	110	105	-5
Wheat	No	East	Corn	120	130	130	0
Wheat	Yes	East	Corn	163	190	194	4
Wheat	No	East	Wheat	55	70	70	0
Wheat	Yes	East	Wheat	75	110	105	-5
Corn	No	East	Corn	120	130	130	0
Corn	Yes	East	Corn	163	190	194	4
Corn	No	East	Wheat	55	70	70	0
Corn	Yes	East	Wheat	75	110	105	-5

Table 4-1: Comparison of KSU Soil Testing Laboratory and NAPP nitrogen recommendations

the recommendations. In order to compare recommendations between the two systems, all spatial variability factors are eliminated from the NAPP system. This is accomplished by using a uniform yield rate and soil type across the field. Also, a non-sandy soil is used. The differences in the recommendations are shown in Table 4-1. The NAPP system's recommendations are within +/- 5 lbs/Acre nitrogen for all conditions tested. This is partially due to the STL rounding to the nearest ten's digit, where as NAPP rounds to the nearest whole number. The error can also be attributed to the adjustment in the STL's recommendations (See Appendix E). This adjustment is simulated in the NAPP system. Note, that if the NAPP recommendations are rounded to the nearest ten's digit, the recommendations are the same.

4.3 Sample Run

A sample run was done using the maps shown in Figures 4-1 and 4-2. This field was assumed to be located in Riley county. The previous crop was wheat with an average yield of 51 bu/Acre. The soil nitrogen content was assumed to be 4 ppm. The input file containing the combined maps and field information is shown in Appendix D. The intended crop was non-irrigated wheat with a yield goal of 60

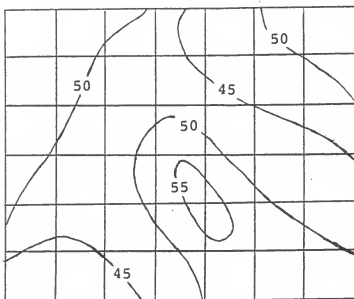


Figure 4-1: Sample Yield Rate Map

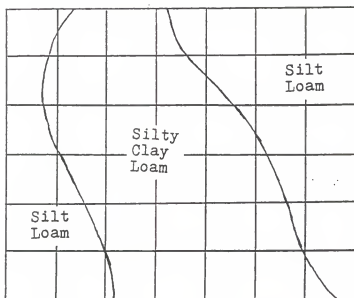


Figure 4-2: Sample Soil Type Map

86	86	81	72	69	72	77
86	83	77	77	70	69	72
86	79	79	84	79	74	70
83	77	81	90	86	77	77
74	74	79	86	91	84	83
69	69	72	81	86	86	86

Figure 4-3: Resulting Recommended Nitrogen Rate Map

bu/Acre. The recommended nitrogen rate map produced by the NAPP system is shown in Figure 4-3. The output file containing the recommended nitrogen rate map is shown in Appendix D. The average recommended nitrogen rate was 79 lbs/Acre. If a uniform rate had been applied across the field the recommended nitrogen rate would have been 79 lbs/Acre, also. Though the overall recommended nitrogen rate was the same in this case, the areas of the field requiring more nitrogen will receive more and the areas requiring less nitrogen will receive less. This will maximize crop production and reduce the environmental impact of applying the nitrogen fertilizer.

5. Other Artificial Intelligent Implementations

5.1 Truth Maintenance Systems

A reasoning system, such as the Intelligent Chemical Recommendation and Control System, may be broken down into two components, the problem solver and a truth maintenance system (TMS) [20,21]. The problem solver contains the knowledge base and the inferencing strategies needed to solve the problem. The TMS records and manages all inferences and conclusions made by the problem solver. The TMS provides three functions for the reasoning system. First, it serves as storage for all inferences made, so that none are repeated. Second, it allows the problem solver to use non-monotonic reasoning. Third, the TMS manages the inferencing database, keeping it free of contradictions introduced with non-monotonic reasoning. This allows the reasoning system to remove or change portions of the reasoning process dependent on the problem being solved.

Truth Maintenance Systems are useful in optimization problems. In the recommendation portion of an Intelligent Recommendation and Applicator Control System many opposing factors exist. A TMS allows for a search of all possible

situations, optimizing the recommendation for the factors present. The system then optimizes to both economical and field related factors. The optimal solution to the recommendation portion requires the non-monotonic reasoning provided with TMS.

5.2 Neural Networks

Neural networks are simplified models of the human nervous system, which exhibit the ability to learn, generalize and abstract data and relationships [22]. Neural networks consist of a computer system made up of simple, highly interconnected elements which process data using a dynamic state response. Neural networks can be either single-layered or multi-layered. Single-layer networks can be used for pattern recognition and classification problems. Multi-layer networks can be used to convert patterns from one format to another.

Neural networks have applications in both the input and control portions of an Intelligent Chemical Recommendation and Applicator Control System. Since all spatial variability factors are in the form of maps which must be combined into one map, a multi-layer network can be used to combine all the different maps into one map of the

field. The control system can use a neural network to convert the recommended chemical rate into an appropriate applicator control signal. Both networks can be trained using computer simulated data. Once trained, the networks can then be used to enhance the performance of the system.

6. Future Work

1. An input system needs to be developed to incorporate spatial variability factor maps into one map of the field. This system should consist of a geographical information system. Also, an algorithm to convert sensor data from the KSU Agriculture Engineering Department's yield mapping system to a usable yield map for the input system needs to be developed.

2. Continued development of the control system is needed. An actual controller should be developed that would allow for operator intervention and control. Its inputs should include the following: the applicator vehicle's present location and ground speed; the applied chemical rate from the recommendation system; the type of fertilizer being applied; and, the type of applicator being used.

3. The intelligent nitrogen recommendation and applicator control system could be modified to include other factors, such as moisture content, tillage practices, and so forth. Also, a different approach, other than using the nitrogen rate recommendation equation, could be investigated.

4. More studies are needed in the area of spatial variability within the field to allow for a more competent recommendation system to be developed.

5. Other intelligent recommendation and applicator control systems could be developed for use in site-specific crop management.

6. Many systems that recommend and apply fertilizer and herbicides on a site by site basis are already available. Studies with these systems show increased profits due to tailoring inputs to specific sites [23]. Some systems can measure the organic matter and nitrogen content on the go. All these systems should be investigated to determine what has already been done and how artificial intelligence techniques can enhance these systems.

7. Conclusions

1. The intelligent chemical recommendation and applicator control system structure consists of an input system, a recommendation system, and a control system. This structure can be used to create individual systems to aide the producer in site-specific crop management.

2. The system using nitrogen demonstrates the intelligent chemical recommendation and applicator control system's functionality. The intelligent nitrogen recommendation and applicator control system is a simple-minded system with only two spatial variability factors, namely yield rate and soil type. This system uses the same knowledge as the KSU Soil Testing Laboratory's recommendation software contains. This system has an algorithmic equation and no heuristic functions in its knowledge base. In order for this system to be effective in site-specific crop management, many other factors must be included in the algorithmic equation and in heuristic functions.

3. Texas Instrument's Personal Consultant Plus development tools provide an adequate environment for implementing intelligent chemical recommendation and applicator control systems. Its useful features include: frame based reasoning; graphic images for visual

interaction with the user; external language interfacing;
and, process control capabilities.

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APPENDIX A
Intelligent Nitrogen Recommendation and
Applicator Control System Knowledge Base Listing

Appendix A contains the knowledge base listing of the NAPP system implemented using PC Plus. This listing was produced by PC Plus. The first portion is general information about the knowledge base. Included in the general information are the variables used by PC Plus and the names of the images used by PC Images. The rest of the listing contains information about each frame. Each frame's properties, parameters, and rules are presented. The frames are listed in the following order: NAPP, FUNCTION, INPUT, ANALYZE, SITE, and APPLY.

DOMAIN :: NAPP
ROOT FRAME :: NAPP

=====
Global KB data
=====

FRAME STRUCTURE ::
 NAPP
 FUNCTION
 INPUT
 ANALYZE
 SITE
 APPLY

KB Files :: (SITE nap1.k1 APPLY nap1.k2 INPUT nap1.k4
 FUNCTION nap1.k5 ANALYZE nap1.k3)

Parameter groups :: (SITE-PARMS APPLY-PARMS ANALYZE-
 PARMS INPUT-PARMS FUNCTION-PARMS
 NAPP-PARMS)

Rule groups :: (SITE-RULES APPLY-RULES ANALYZE-RULES
 INPUT-RULES FUNCTION-RULES NAPP-RULES
 META-RULES)

Number of rules :: 35

Number of meta-rules :: 0

Variables :: (DOMAIN)

TEXTAGS :: ()

Functions :: ()

=====
IMAGES
=====

Cluster #1
=====

Background Graphics Pictures :: NAP1_ICR

Parameter Name :: INTENDED_CROP

 Image Name :: I-ICROP
 Image Type :: Selection Region
 Expect Value :: User Defined
 Values :: WHEAT CORN
 Bordered :: NO
 Text/Border Color :: Green
Post Access Operation :: Remove Cluster
 Label :: ()

Cluster #2

=====

Background Graphics Pictures ::

Parameter Name :: N_RATE

Image Name :: INRATE
Image Type :: Vert. Bar Graph
Expect Value :: Numeric Range
Range :: Min: 0
Max: 200
Increment: 10
Initial: 0
Bordered :: YES
Text/Border Color :: Light Blue
Post Access Operation :: Leave Cluster
Label :: Recommended Nitrogen (lbs/Acre)

Parameter Name :: LAT

Image Name :: ILAT
Image Type :: Digital Disp. Panel
Expect Value :: Numeric Range
Range :: Min: 0
Max: 20
Increment: 1
Initial: 0
Bordered :: YES
Text/Border Color :: Intensified White
Post Access Operation :: Leave Cluster
Label :: Relative North-South Location

Parameter Name :: LONG

Image Name :: ILONG
Image Type :: Digital Disp. Panel
Expect Value :: Numeric Range
Range :: Min: 0
Max: 20
Increment: 1
Initial: 0
Bordered :: YES
Text/Border Color :: Intensified White
Post Access Operation :: Leave Cluster
Label :: Relative East-West Location

```

Parameter Name :: ZERO-N
-----
      Image Name :: IZERON
      Image Type :: Display Panel
      Expect Value :: Single Line Input
      Values ::
      Bordered :: NO
      Text/Border Color :: Light Green
Post Access Operation :: Remove after Keyboard Input
      Label :: ( )

```

Cluster #3

=====

Background Graphics Pictures :: NAP1_YG

```

Parameter Name :: WESTERN_YG
-----
      Image Name :: IWYG
      Image Type :: Digital Disp. Panel
      Expect Value :: Numeric Range
      Range :: Min: 0
               Max: 200
               Increment: 20
               Initial: 10
      Bordered :: YES
      Text/Border Color :: Magenta
Post Access Operation :: Leave Cluster
      Label :: Western Yield Goal

```

```

Parameter Name :: CENTRAL_YG
-----
      Image Name :: ICYG
      Image Type :: Digital Disp. Panel
      Expect Value :: Numeric Range
      Range :: Min: 0
               Max: 200
               Increment: 10
               Initial: 10
      Bordered :: YES
      Text/Border Color :: Magenta
Post Access Operation :: Leave Cluster
      Label :: Central Yield Goal

```

```

Parameter Name :: EASTERN_YG
-----
      Image Name :: IEYG
      Image Type :: Digital Disp. Panel
      Expect Value :: Numeric Range
      Range :: Min: 0

```

```

Max: 200
Increment: 10
Initial: 10
      Bordered :: YES
Text/Border Color :: Magenta
Post Access Operation :: Leave Cluster
      Label :: Eastern Yield Goal

Parameter Name :: YG
-----
      Image Name :: IYG
      Image Type :: Digital Disp. Panel
Expect Value :: Numeric Range
      Range :: Min: 0
              Max: 200
              Increment: 1
              Initial: 0
      Bordered :: NO
Text/Border Color :: Green
Post Access Operation :: Remove Cluster
      Label :: ()

```

```

=====
VARIABLES
=====

```

```

DOMAIN
VALUE :: NAPP

```

```
=====
Frame :: NAPP
=====
```

```
IDENTIFIER :: NAPP-
TRANSLATION :: (the top frame for the intelligent
                nitrogen recommendation and applicator
                control system )
GOALS :: (FINISH)
PROMPTEVER :: ("Welcome to the Intelligent Nitrogen
               Recommendation and Applicator Control
               System." :line 4 "Please follow all
               instructions." )
PARMGROUP :: NAPP-PARMS
RULEGROUPS :: (NAPP-RULES)
OFFSPRING :: (FUNCTION)
NAPP-PARMS  :: (DUMMY FINISH)
NAPP-RULES  :: (RULE001)
```

```
=====
NAPP-PARMS
=====
```

```
DUMMY
=====
```

```
TRANSLATION :: (A dummy parameter used to initiate
                the knowledge based system. )
TYPE :: YES/NO
USED-BY :: (RULE001)
DEFAULT :: (YES)
```

```
FINISH
=====
```

```
TRANSLATION :: (goal used to drive the knowledge
                base system)
TYPE :: YES/NO
UPDATED-BY :: (RULE001)
```

```
=====
NAPP-RULES
=====
```

RULE001

=====

SUBJECT :: NAPP-RULES

EXPLANATION :: (instantiates the function frame)

IF :: (DUMMY)

THEN :: (FINISH AND CONSIDERFRAME FUNCTION AND PRINT
"Thank you for using the Intelligent
Nitrogen Recommendation and Applicator
Control System." :LINE 4 Have a nice day.)

```

=====
Frame :: FUNCTION
=====

```

```

IDENTIFIER :: FUNCTION-
TRANSLATION :: (Determines which operation should be
                performed.)
PARENTS :: (NAPP)
GOALS :: (OPERATION)
PROMPT2ND :: (Do you wish to perform another
              operation?)
FINAL-FUNCTIONS :: (DO-ALL (SET-OPTIONS OFF ALL))
PARMGROUP :: FUNCTION-PARMS
RULEGROUPS :: (FUNCTION-RULES)
OFFSPRING :: (INPUT ANALYZE APPLY)
FUNCTION-PARMS :: (APPLY-FILE-NAME OPERATION OPTIONS)
FUNCTION-RULES :: (RULE002 RULE003 RULE004 RULE005)

```

```

=====
FUNCTION-PARMS
=====

```

```

APPLY-FILE-NAME
=====

```

```

TRANSLATION :: (the filename of the recommended
                nitrogen rate used by the control
                subsystem )
PROMPT :: (What is name of the file containing the
           recommended nitrogen rate map? )
TYPE :: SINGLEVALUED
EXPECT :: SINGLE-LINE-INPUT

```

```

OPERATION
=====

```

```

TRANSLATION :: (The operation to be done.)
TYPE :: SINGLEVALUED
EXPECT :: (INPUT ANALYZE APPLY EXIT)
UPDATED-BY :: (RULE002 RULE003 RULE005 RULE004)

```

```

OPTIONS
=====

```

```

TRANSLATION :: (the desired operation)
PROMPT :: (Choose desired operation from list
           below.)
TYPE :: SINGLEVALUED
EXPECT :: (INPUT ANALYZE APPLY EXIT)
USED-BY :: (RULE002 RULE003 RULE005 RULE004)

```

```

=====
FUNCTION-RULES
=====

```

RULE002

```

=====
SUBJECT :: FUNCTION-RULES
EXPLANATION :: (exits frame)
IF      :: (OPTIONS = EXIT)
THEN    :: (OPERATION = EXIT)

```

RULE003

```

=====
SUBJECT :: FUNCTION-RULES
EXPLANATION :: (instantiates the input frame)
IF      :: (OPTIONS = INPUT)
THEN    :: (OPERATION = INPUT AND PRINT Ready to input
            data. AND CONSIDERFRAME INPUT )

```

RULE004

```

=====
SUBJECT :: FUNCTION-RULES
EXPLANATION :: (instantiates the analyze frame)
IF      :: (OPTIONS = ANALYZE)
THEN    :: (OPERATION = ANALYZE AND PRINT "Beginning
            nitrogen rate calculations." AND
            SET-OPTIONS ON NO-RETURN-KEY AND
            CONSIDERFRAME ANALYZE )

```

RULE005

```

=====
SUBJECT :: FUNCTION-RULES
EXPLANATION :: (instantiates the apply frame)
IF      :: (OPTIONS = APPLY)
THEN    :: (OPERATION = APPLY AND PRINT Ready to apply
            nitrogen. AND SET-OPTIONS ON NO-RETURN-KEY
            OFF OVERRIDE AND CONSIDERFRAME APPLY AND
            (E (NOUTPUT 0)) )

```



```
=====
      Frame :: INPUT
=====
```

```
IDENTIFIER :: INPUT-
TRANSLATION :: (a geographical information system used
                to collect spatial field data )
PARENTS :: (FUNCTION NAP)
DISPLAYRESULTS :: YES
PARMGROUP :: INPUT-PARMS
RULEGROUPS :: (INPUT-RULES)
INPUT-PARMS  :: ( )
INPUT-RULES  :: ( )
```

```
=====
Frame :: ANALYZE
=====
```

```
IDENTIFIER :: ANALYZE-
TRANSLATION :: (the recommendation system, holds field
                 specific data)
PARENTS :: (FUNCTION NAP)
GOALS :: (FIELD-DATA DATAIN REQ_N)
PROMPT2ND :: (Do you wish to consider another field?)
PARMGROUP :: ANALYZE-PARMS
RULEGROUPS :: (ANALYZE-RULES)
OFFSPRING :: (SITE)
ANALYZE-PARMS :: (ADUMMY CENTRAL YG COUNTY CROP TYPE
                  DATAIN EASTERN YG FIELD-DATA
                  INPUT-FILE INTENDED CROP IRRIGATION
                  NX1 NX2 N PROF OUTPUT-FILE PPM N
                  PREVIOUS CROP REGION REQ_N SITES
                  TOTAL WESTERN YG YG YIELD_AVG
                  YIELD GOAL Y VS N )
ANALYZE-RULES :: (RULE006 RULE007 RULE008 RULE009
                  RULE010 RULE011 RULE012 RULE013
                  RULE020 RULE021 RULE022 RULE023
                  RULE024 RULE028 RULE029 RULE030
                  RULE032 RULE033 RULE034 RULE035 )
```

```
=====
ANALYZE-PARMS
=====
```

```
ADUMMY
=====
```

```
TRANSLATION :: (dummy parameter for the analyze
                 frame)
TYPE :: YES/NO
USED-BY :: (RULE032 RULE024)
DEFAULT :: (YES)
```

```
CENTRAL YG
=====
```

```
TRANSLATION :: (The default value for YIELD_GOAL in
                 Central KS.)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
ANTECEDENT-IN :: (RULE029)
```

```

CONTAINED-IN :: (RULE011 RULE029)
RANGE :: (0 200)
IMAGE-NAME :: ICYG

COUNTY
=====
TRANSLATION :: (the county in Kansas in which the
                field is located)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE024)
ANTECEDENT-IN :: (RULE034 RULE035 RULE033)

CROP_TYPE
=====
TRANSLATION :: (the intended crop type)
TYPE :: SINGLEVALUED
EXPECT :: (GRAIN ROW LEGUME)

DATAIN
=====
TRANSLATION :: (goal for reading in the nitrogen
                rate recommendation equation
                coefficients from NEQN.DAT )
TYPE :: YES/NO
UPDATED-BY :: (RULE006 RULE007 RULE008 RULE009)

EASTERN_YG
=====
TRANSLATION :: (The default value for YIELD_GOAL in
                Eastern KS.)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
ANTECEDENT-IN :: (RULE028)
CONTAINED-IN :: (RULE010 RULE028)
IMAGE-NAME :: IEYG
RANGE :: (0 200)

FIELD-DATA
=====
TRANSLATION :: (goal for reading in the field
                specific data from the field map )
TYPE :: YES/NO
UPDATED-BY :: (RULE024)

INPUT-FILE
=====
TRANSLATION :: (the filename of the field map)
PROMPT :: (What is the name of the file containing
           the map of the desired field? )

```

```

TYPE :: SINGLEVALUED
EXPECT :: SINGLE-LINE-INPUT

INTENDED_CROP
=====
TRANSLATION :: (the intended crop for the field)
TYPE :: SINGLEVALUED
EXPECT :: USER-DEFINED
USED-BY :: (RULE006 RULE007 RULE008 RULE009)
IMAGE-NAME :: I-ICROP

IRRIGATION
=====
PROMPT :: (Is this field irrigated?)
TYPE :: YES/NO
USED-BY :: (RULE006 RULE007 RULE008 RULE009)

NX1
===
TRANSLATION :: (A coefficeint in the nitrogen
                recommendation equation.)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
USED-BY :: (RULE015 RULE019)
CONTAINED-IN :: (RULE015)

NX2
===
TRANSLATION :: (A default value for PPM_N.)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
CONTAINED-IN :: (RULE013)

N_PROF
=====
TRANSLATION :: (the nitrogen in ppm in the soil
                profile)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE013 RULE020 RULE024)
USED-BY :: (RULE018 RULE014)
CONTAINED-IN :: (RULE014)

OUTPUT-FILE
=====
TRANSLATION :: (the name of the file which will
                contain the recommended nitrogen
                rate map )
PROMPT :: (What is the desired filename for the
            recommended nitrogen rate map? )

```

TYPE :: SINGLEVALUED
EXPECT :: SINGLE-LINE-INPUT

PPM_N
=====

TRANSLATION :: (The amount of nitrogen found in the
soil sample.)
PROMPT :: (What was the nitrogen content of the
soil?)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
ASKFIRST :: YES
USED-BY :: (RULE013 RULE020)
CONTAINED-IN :: (RULE020)

PREVIOUS_CROP
=====

TRANSLATION :: (The previous year's crop.)
TYPE :: SINGLEVALUED
EXPECT :: USER-DEFINED
UPDATED-BY :: (RULE024)
USED-BY :: (RULE022 RULE023)

REGION
=====

TRANSLATION :: (The area of the state the field is
located.)
TYPE :: SINGLEVALUED
EXPECT :: (EASTERN CENTRAL WESTERN)
UPDATED-IN :: (RULE034 RULE035 RULE033)
ANTECEDENT-IN :: (RULE028 RULE029 RULE030)
USED-BY :: (RULE010 RULE011 RULE012)

REQ_N
=====

TRANSLATION :: (the average recommended nitrogn rate
for the field)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE032)
CONTAINED-IN :: (RULE032)

SITES
=====

TRANSLATION :: (the number of sites in the field)
TYPE :: SINGLEVALUED
UPDATED-IN :: (RULE031)
DEFAULT :: (0)
CONTAINED-IN :: (RULE032 RULE031)

TOTAL

=====

TRANSLATION :: (the total of the recommended
nitrogen rates for all the sites)
TYPE :: SINGLEVALUED
UPDATED-IN :: (RULE031)
DEFAULT :: (0)
CONTAINED-IN :: (RULE032 RULE031)

WESTERN_YG

=====

TRANSLATION :: (The default value for YIELD_GOAL in
western KS.)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
ANTECEDENT-IN :: (RULE030)
CONTAINED-IN :: (RULE012 RULE030)
IMAGE-NAME :: IWYG
RANGE :: (0 200)

YG

==

TRANSLATION :: (The intermediate yield goal)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
USED-BY :: (RULE010 RULE011 RULE012 RULE021)
CONTAINED-IN :: (RULE021 RULE028 RULE029 RULE030)
IMAGE-NAME :: IYG
RANGE :: (0 200)

YIELD_AVG

=====

TRANSLATION :: (the average yield for the previous
crop)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
UPDATED-BY :: (RULE024)
USED-BY :: (RULE018 RULE014)
CONTAINED-IN :: (RULE014)

YIELD_GOAL

=====

TRANSLATION :: (the yield goal for the intended
crop)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
UPDATED-BY :: (RULE010 RULE011 RULE012 RULE021)
USED-BY :: (RULE015 RULE019)
CONTAINED-IN :: (RULE015)

RANGE :: (0 300)

Y_VS_N

=====

TRANSLATION :: (The amount of nitrogen taken per
unit of crop produced.)

TYPE :: SINGLEVALUED

EXPECT :: POSITIVE-NUMBER

UPDATED-BY :: (RULE022 RULE023)

USED-BY :: (RULE018 RULE014)

CONTAINED-IN :: (RULE014)

=====

ANALYZE-RULES

=====

RULE006

=====

SUBJECT :: ANALYZE-RULES

EXPLANATION :: (reads in recommendation equation
coefficients for non-irrigated corn)

IF :: (INTENDED_CROP = CORN AND ! IRRIGATION)

THEN :: (DATAIN AND IMPORT (QUOTE (NEQDATA (QUOTE
CORN-D))) AND CONSIDERFRAME SITE)

RULE007

=====

SUBJECT :: ANALYZE-RULES

EXPLANATION :: (reads in recommendation equation
coefficients for irrigated corn)

IF :: (INTENDED_CROP = CORN AND IRRIGATION)

THEN :: (DATAIN AND IMPORT (QUOTE (NEQDATA (QUOTE
CORN-I))) AND CONSIDERFRAME SITE)

RULE008

=====

SUBJECT :: ANALYZE-RULES

EXPLANATION :: (reads in recommendation equation
coefficients for non-irrigated
wheat)

IF :: (INTENDED_CROP = WHEAT AND ! IRRIGATION)

THEN :: (DATAIN AND IMPORT (QUOTE (NEQDATA (QUOTE
WHEAT-D))) AND CONSIDERFRAME SITE)

RULE009

=====

SUBJECT :: ANALYZE-RULES

EXPLANATION :: (reads in recommendation equation
coefficients for irrigated wheat)

```

IF      :: (INTENDED_CROP = WHEAT AND IRRIGATION)
THEN    :: (DATAIN AND IMPORT (QUOTE (NEQDATA (QUOTE
      WHEAT-I))) AND CONSIDERFRAME SITE )

RULE010
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns default value for yield goal
                if in eastern Kansas )
IF      :: (YG = 0 AND REGION = EASTERN)
THEN    :: (YIELD_GOAL = (VALUE EASTERN_YG))

RULE011
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns default value for yield goal
                if in central Kansas )
IF      :: (YG = 0 AND REGION = CENTRAL)
THEN    :: (YIELD_GOAL = (VALUE CENTRAL_YG))

RULE012
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns default value for yield goal
                if in western Kansas )
IF      :: (YG = 0 AND REGION = WESTERN)
THEN    :: (YIELD_GOAL = (VALUE WESTERN_YG))

RULE013
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns default value for the amount
                of nitrogen in the soil profile )
IF      :: (PPM_N <= 0)
THEN    :: (N_PROF = (VALUE NX2))

RULE020
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns a value to the amount of
                nitrogen in the soil profile if
                known )
IF      :: (PPM_N > 0)
THEN    :: (N_PROF = (VALUE PPM_N))

RULE021
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns the yield goal for the field

```



```

                                if known)
IF      :: (YG > 0)
THEN    :: (YIELD_GOAL = (VALUE YG))

RULE022
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns Y_vs_N if previous crop is
                corn)
IF      :: (PREVIOUS_CROP = CORN)
THEN    :: (Y_VS_N = 2.55)

RULE023
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (assigns Y_vs_N if previous crop is
                wheat)
IF      :: (PREVIOUS_CROP = WHEAT)
THEN    :: (Y_VS_N = 1.75)

RULE024
=====
SUBJECT :: ANALYZE-RULES
EXPLANATION :: (reads in field-specific data from
                the field map)
IF      :: (ADUMMY)
THEN    :: (FIELD-DATA AND IMPORT (QUOTE (DOS-FILE-IN
                (VAL1 FRAME INPUT-FILE ) N_PROF
                PREVIOUS_CROP YIELD_AVG COUNTY ) ) )

RULE028
=====
SUBJECT :: ANALYZE-RULES
ANTECEDENT :: YES
EXPLANATION :: (presets yg to eastern_yg)
IF      :: (REGION = EASTERN AND EASTERN_YG IS KNOWN)
THEN    :: (PRESET-IMAGE YG EASTERN_YG)

RULE029
=====
SUBJECT :: ANALYZE-RULES
ANTECEDENT :: YES
EXPLANATION :: (presets yg to central_yg)
IF      :: (REGION = CENTRAL AND CENTRAL_YG IS KNOWN)
THEN    :: (PRESET-IMAGE YG CENTRAL_YG)

RULE030
=====
SUBJECT :: ANALYZE-RULES

```

```

ANTECEDENT :: YES
EXPLANATION :: (presets yg to western_yg)
IF      :: (REGION = WESTERN AND WESTERN_YG IS KNOWN)
THEN    :: (PRESET-IMAGE YG WESTERN_YG)

```

RULE032

=====

```

SUBJECT :: ANALYZE-RULES
EXPLANATION :: (calculates the the average nitrogen
                rate for the field)
IF      :: (ADUMMY)
THEN    :: (REQ_N = (TOTAL / SITES) AND PRINT :LINE
            "The average recommended nitrogen rate for
            the field is" (FIX REQ_N) lbs/A. )

```

RULE033

=====

```

SUBJECT :: ANALYZE-RULES
ANTECEDENT :: YES
EXPLANATION :: (checks for county in eastern region)
IF      :: (COUNTY IS KNOWN AND (E (MEMBER (VAL1 FRAME
        COUNTY) (QUOTE (AL AN AT BB BR CS CQ CK CF
        CR DP DG EK FR GE GW JA JF JO LB LV LN LY
        MS MI MG MR NM NO PT RL SN WB WL WO WY ) )
        ) ) )
THEN    :: (REGION = EASTERN)

```

RULE034

=====

```

SUBJECT :: ANALYZE-RULES
ANTECEDENT :: YES
EXPLANATION :: (checks for county in central region)
IF      :: (COUNTY IS KNOWN AND (E (MEMBER (VAL1 FRAME
        COUNTY) (QUOTE (BA BT BU CY CD CL DK EW HP
        HV KM LC MN MP MC OB OT PR RN RP RC SA SG
        SM SF SU WS ) ) ) ) )
THEN    :: (REGION = CENTRAL)

```

RULE035

=====

```

SUBJECT :: ANALYZE-RULES
ANTECEDENT :: YES
EXPLANATION :: (checks for county in western region)
IF      :: (COUNTY IS KNOWN AND (E (MEMBER (VAL1 FRAME
        COUNTY) (QUOTE (CN CA CM DC ED EL FI FO GO
        GH GT GY GL HM HS HG KE KW LE LG ME MT NS
        NT PN PL RA RO RU SC SW SD SH ST SV TH TR
        WA WH ) ) ) ) )
THEN    :: (REGION = WESTERN)

```

=====

Frame :: SITE

=====

IDENTIFIER :: SITE-

TRANSLATION :: (holds the data for each specific site
and calculates and stores the
recommended nitrogen rate)

PARENTS :: (ANALYZE FUNCTION NAP)

GOALS :: (NREC)

PROMPT1ST :: (PREMISE)

PROMPT2ND :: (PREMISE)

PREMISE :: (\$AND
(IMPORT

('
(DOS-FILE-IN
(VAL1 FRAME INPUT-FILE) LATITUDE
LONGITUDE SITE_YIELD SOIL_TEXTURE))
)

FINAL-FUNCTIONS :: (DELETE-DYN-FRAME SITE)

PARMGROUP :: SITE-PARMS

RULEGROUPS :: (SITE-RULES)

SITE-PARMS :: (LATITUDE LONGITUDE NREC N_CONC
SITE_YIELD SOIL_TEXTURE
SOIL_TEXT_FACTOR)

SITE-RULES :: (RULE014 RULE015 RULE016 RULE017
RULE018 RULE019 RULE031)

=====

SITE-PARMS

=====

LATITUDE

=====

TRANSLATION :: (the relative North-South location of
the site)

TYPE :: SINGLEVALUED

EXPECT :: NUMBER

CONTAINED-IN :: (RULE015)

LONGITUDE

=====

TRANSLATION :: (the relative East-West location of
the site)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
CONTAINED-IN :: (RULE015)

NREC

=====

TRANSLATION :: (The recommended nitrogen to be
applied at this site)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
UPDATED-BY :: (RULE019 RULE015)
ANTECEDENT-IN :: (RULE031)
CONTAINED-IN :: (RULE031 RULE015)

N_CONC

=====

TRANSLATION :: (the nitrogen concentration in soil
in lbs/A)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE018 RULE014)
USED-BY :: (RULE019 RULE015)
CONTAINED-IN :: (RULE015)

SITE_YIELD

=====

TRANSLATION :: (The yield at the present site.)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
USED-BY :: (RULE018 RULE014)
CONTAINED-IN :: (RULE014)

SOIL_TEXTURE

=====

TRANSLATION :: (the soil texture at the site)
TYPE :: SINGLEVALUED
EXPECT :: (CLAY SILTY_CLAY SANDY_CLAY CLAY LOAM
SILTY_CLAY LOAM SANDY_CLAY LOAM LOAM
SANDY_LOAM SILT_LOAM SAND LOAMY_SAND
SILT)
USED-BY :: (RULE016 RULE017)

SOIL_TEXT_FACTOR

=====

TRANSLATION :: (A coefficient in the nitrogen
recommendation equation.)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER

UPDATED-BY :: (RULE016 RULE017)
CONTAINED-IN :: (RULE015)

=====
SITE-RULES
=====

RULE014

=====

SUBJECT :: SITE-RULES
EXPLANATION :: (determines the amount of nitrogen in
the soil at the site in lbs/A)
IF :: ((7.5 * N PROF) >= (Y_VS_N * (SITE_YIELD -
YIELD_AVG)))
THEN :: (N CONC = ((7.5 * N PROF) - (Y_VS_N *
(SITE_YIELD - YIELD_AVG))))

RULE015

=====

SUBJECT :: SITE-RULES
EXPLANATION :: (determines the recommended nitrogen
rate at the site in lbs/A)
IF :: ((NX1 * YIELD GOAL) >= N CONC)
THEN :: (NREC = (FIX ((NX1 * YIELD GOAL) - N CONC)
* SOIL TEXT FACTOR) + 4.5) AND EXPORT
(QUOTE (DOS-FILE-OUT (LATITUDE LONGITUDE
NREC) (VAL1 FRAME OUTPUT-FILE) APPEND))
AND PRINT "The recommended nitrogen rate at
site" LATITUDE , LONGITUDE "is" NREC
"lbs/A.")

RULE016

=====

SUBJECT :: SITE-RULES
EXPLANATION :: (assigns the soil texture factor for
non-sandy soils)
IF :: (! (SOIL_TEXTURE = SANDY OR SOIL_TEXTURE =
SANDY CLAY OR SOIL_TEXTURE =
SANDY CLAY LOAM OR SOIL_TEXTURE =
SANDY LOAM OR SOIL_TEXTURE = LOAMY_SAND))
THEN :: (SOIL_TEXT_FACTOR = 1.)

RULE017

=====

SUBJECT :: SITE-RULES
EXPLANATION :: (assigns the soil texture factor for
sandy soils)
IF :: (SOIL_TEXTURE = SANDY OR SOIL_TEXTURE =

```

        SANDY_CLAY OR SOIL_TEXTURE =
        SANDY_CLAY_LOAM OR SOIL_TEXTURE =
        SANDY_LOAM OR SOIL_TEXTURE = LOAMY_SAND )
    THEN :: (SOIL_TEXT_FACTOR = 1.1)

```

RULE018

=====

```

    SUBJECT :: SITE-RULES
    EXPLANATION :: (sets the amount of nitrogen in the
                     soil profile at the site to zero if
                     determined to be negative )
    IF      :: ((7.5 * N_PROF) < (Y_VS_N * (SITE_YIELD -
                     YIELD_AVG)))
    THEN    :: (N_CONC = 0.)

```

RULE019

=====

```

    SUBJECT :: SITE-RULES
    EXPLANATION :: (sets the recommended nitrogen at the
                     site to zero if determined to be
                     negative )
    IF      :: ((NX1 * YIELD_GOAL) < N_CONC)
    THEN    :: (NREC = 0. AND EXPORT (QUOTE (DOS-FILE-OUT
                     (LATITUDE LONGITUDE NREC ) (VAL1 FRAME
                     OUTPUT-FILE) APPEND ) ) )

```

RULE031

=====

```

    SUBJECT :: SITE-RULES
    ANTECEDENT :: YES
    EXPLANATION :: (totals the nitrogen rates being
                     applied and the number of sites )
    IF      :: (NREC IS KNOWN)
    THEN    :: (TOTAL = (TOTAL + NREC) AND SITES =
                     (SITES + 1))

```

```
=====
Frame :: APPLY
=====
```

```
IDENTIFIER :: APPLY-
TRANSLATION :: (control system used to apply the
                 fertilizer)
PARENTS :: (FUNCTION NAP)
GOALS :: (GETN APPLIED)
PROMPT1ST :: (PREMISE)
PROMPT2ND :: (PREMISE)
PREMISE :: ($AND
            (IMPORT
             ('
              (DOS-FILE-IN "site.dat" LAT LONG)))
            (E
             (OPTION? OFF OVERRIDE)))
FINAL-FUNCTIONS :: (DELETE-DYN-FRAME APPLY)
PARMGROUP :: APPLY-PARMS
RULEGROUPS :: (APPLY-RULES)
APPLY-PARMS :: (APPLIED GETN LAT LONG N_RATE ZERO-N)
APPLY-RULES :: (RULE025 RULE026 RULE027)
```

```
=====
APPLY-PARMS
=====
```

```
APPLIED
=====
TRANSLATION :: (goal used to output the nitrogen
                rate to an external device )
TYPE :: YES/NO
UPDATED-BY :: (RULE026 RULE027)
```

```
GETN
=====
TRANSLATION :: (goal used to search the recommended
                nitrogen rate map)
TYPE :: YES/NO
UPDATED-BY :: (RULE025)
```

```
LAT
=====
TRANSLATION :: (the relative latitude of the site)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
```

```

USED-BY :: (RULE025)
RANGE :: (0 20)
IMAGE-NAME :: ILAT

LONG
=====
TRANSLATION :: (the relative longitude of the site)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
USED-BY :: (RULE025)
RANGE :: (0 20)
IMAGE-NAME :: ILONG

N RATE
=====
TRANSLATION :: (the applied nitrogen rate)
TYPE :: SINGLEVALUED
EXPECT :: NUMBER
USED-BY :: (RULE026 RULE027)
CONTAINED-IN :: (RULE025)
IMAGE-NAME :: INRATE
RANGE :: (0 200)

ZERO-N
=====
TRANSLATION :: (alarm for zero nitrogen level)
TYPE :: SINGLEVALUED
EXPECT :: SINGLE-LINE-INPUT
UPDATED-BY :: (RULE026)
IMAGE-NAME :: IZERON

=====
      APPLY-RULES
=====

RULE025
=====
SUBJECT :: APPLY-RULES
EXPLANATION :: (search the nitrogen map and read in
                the nitrogen rate for the site )
IF :: (LAT IS KNOWN AND LONG IS KNOWN)
THEN :: (GETN AND IMPORT (QUOTE (GETNRATE (VAL1
      FRAME LAT) (VAL1 FRAME LONG ) (VAL1 FRAME
      APPLY-FILE-NAME) ) ) AND SET-IMAGE N_RATE
      N_RATE )

RULE026
=====

```



```

SUBJECT :: APPLY-RULES
EXPLANATION :: (send nitrogen rate of 0 to external
                device and sound alarm )
IF    :: (N_RATE <= 0)
THEN  :: (APPLIED AND ALARM BEEP AND ZERO-N = "The
          nitrogen rate currently being applied is
          zero." AND (E (NOUTPUT 0)) )

```

RULE027

=====

```

SUBJECT :: APPLY-RULES
EXPLANATION :: (send nitrogen to external device)
IF    :: (N_RATE > 0)
THEN  :: (APPLIED AND (E (NOUTPUT (VAL1 FRAME N_RATE)
                                )))

```

APPENDIX B

User-written PC Scheme functions

Appendix B contains the user-written PC Scheme functions used by the NAPP system. These functions are contained in the NAP1.CST file. Two separate groups of LISP functions are listed in this appendix. The first group is the functions required to obtain the crop dependent nitrogen rate recommendation equation coefficients. The second group is the functions used to search the recommended nitrogen rate map and to output the returned nitrogen rate to an external device.

```

;*****
;* Martin Eis
;* 12 Dec 1988
;*
;* NEQDATA is used with the intelligent nitrogen recommendation
;* and applicator control system (NAPP). It returns a list of
;* the crop dependent coefficients of the nitrogen rate
;* recommendation equation and their values contained in NEQN.DAT
;* to PC Plus via the IMPORT function.
;*****

(DEFINE NEQ_DATA_FILE)
(DEFINE PARAM)
(DEFINE VALUES)
(DEFINE RETURN)

(DEFINE (NEQDATA CROP)
  (SET! NEQ_DATA_FILE (OPEN-INPUT-FILE "NEQN.DAT"))
  (SET! PARAM (READ NEQ_DATA_FILE))
  (SET! RETURN (NEQSEARCH CROP))
  (CLOSE-INPUT-PORT NEQ_DATA_FILE)
  RETURN)

(DEFINE (NEQSEARCH CROP)
  (SET! VALUES (READ NEQ_DATA_FILE))
  (COND ((EQ? CROP (CAR VALUES)) (MERGE (CDR PARAM)
                                           (CDR VALUES))))
  (T (NEQSEARCH CROP))))

(DEFINE (MERGE L1 L2)
  (COND ((NULL? L1) ())
        (T (CONS (LIST (CAR L1) (CAR L2))
                  (MERGE (CDR L1) (CDR L2))))))

;*****
;* Martin Eis
;* 01 Feb 1989
;*
;* The following functions are also used with the NAPP system.
;*
;* GETNRATE receives the present applicator site location and the
;* desired recommended nitrogen rate map. Then, it searches the
;* map for the site and returns the recommended nitrogen rate for
;* that site. This value is sent back to PC Plus via the IMPORT
;* function
;*
;* NOUTPUT receives the nitrogen rate to be applied and sends it

```

```

;* out to port 0x278 using xcall and PC Scheme's XLI feature.
;* The external program is in napio.c.
;*****

(DEFINE N-RATE)
(DEFINE N-FILE)
(DEFINE F-LAT)
(DEFINE F-LONG)
(DEFINE F-N-RATE)

(DEFINE (GETNRATE LAT LONG N-FILE-NAME)
  (SET! N-FILE (OPEN-INPUT-FILE N-FILE-NAME))
  (SET! N-RATE (NSEARCH LAT LONG))
  (CLOSE-INPUT-PORT N-FILE)
  (LIST 'N_RATE N-RATE))

(DEFINE (NSEARCH LAT LONG)
  (SET! F-LAT (READ N-FILE))
  (SET! F-LONG (READ N-FILE))
  (SET! F-N-RATE (READ N-FILE))
  (COND ((EOF-OBJECT? F-LAT) 0.0)
        ((AND (EQ? F-LAT LAT) (EQ? F-LONG LONG))
         F-N-RATE)
        (T (NSEARCH LAT LONG))))

(DEFINE (NOUTPUT N-RATE)
  (XCALL "nap_out" (FLOAT N-RATE)))

```

APPENDIX C

External Interface Software

Appendix C contains the program used to output the nitrogen rate to an external device. The program is written in Microsoft C. This program is provided by PC Scheme as a template for using PC Scheme's External Language Interface feature and has been modified for use with NAPP. The only portions of this program that were modified are the functions which could be called using PC Plus. All other sections of the program remain unchanged. Both input and output of data via an external port are provided by this program. Presently, only the output of data to an external device is used. Data is sent to a display through port 0x0278, which is the LPT2 parallel printer port. The path to the executable C file must be contained in the SCHEME.XLI file.

/******

napio.c

This program is to be used with the Intelligent Nitrogen Recommendation and Applicator Control System (NAPP) implemented in PC Plus. This program provides input and output routines for sending and receiving one byte of data via an external port.

This program was modified for this application from the Microsoft C external language interface program provided with PC Scheme.

Modified by Martin Eis

01 Feb 1989

Note: Before linking this program you will need to use the Macro Assembler to assemble the file GLUE_MS.ASM. The output of the assembler, GLUE_MS.OBJ will then be linked with the object of this file created by MSC.

The command line to compile is:
MSC napio;

The command line to assemble is:
MASM glue_ms;

The command line to link this program is:
LINK napio+glue_ms;

*****/

```
#include "dos.h"
#include "math.h"
#include "stdlib.h"
```

```
#define F_NEAR 0x0001 /* Set model flag to near.      USED */
#define F_INT 0x0002 /* Set int flag to 16 bit.  NOT-USED */
#define F_REL 0x0004 /* Set release env block by ext pgm
                     flag. NOT-USED */
#define F_PAD 0x0008 /* Set parm blocking flag to unblocked.
                     USED */
```

```
#define RT_INTEGER 0 /* Set return type to be an integer.
                     NOT-USED */
#define RT_BOOLEAN 1 /* Set return type to be boolean.
                     NOT-USED */
#define RT_STRING 2 /* Set return type to be a string.
```

```

                                NOT-USED */
#define RT_DOUBLE 3 /* Set the return type to be a float num.
                                USED */

typedef unsigned short WORD;          /* 16-bit unsigned value */

/*****
    Xwait and xbye will contain the actual addresses, XLI entry
    points, that we'll jump to when we call XLI so they need to
    be big enough to hold FAR pointers.
*****/

WORD xwait[2];
WORD xbye[2];

WORD tsize; /* Will contain the length of this program in
             paragraphs. */

struct xli_file_struct {
    WORD id;
    WORD flags;
    WORD table[2];          /* offset in 0, segment in 1 */
    WORD parm_block[2];
    WORD reserved[8];
} file_block;

struct xli_routine_struct {
    WORD select;
    WORD special_service;
    WORD ss_args[8];
    WORD reserved[8];
    WORD return_type;
    double return_value;
    double arg1;
} parm_block;

char table[] =
/*****
    The following string contains the names of the functions that
    can be called from within SCHEME when this file is loaded thru
    XLI.

    0      1
*****/
"nap_out/nap_in/";

```

```

void main()
{
    struct SREGS segregs;

/*****
    These function are defined in the assembly file GLUE MS.ASM
    and are the functions that interface with Schemes XLI.
*****/

    int xli_wait();
    void xli_bye();

    union {
        WORD far * psp_ptr; /* declare as a far 32 bit pointer. */
        WORD half_ptr[2]; /* declare 2 16 bit words for Seg & Off */
    } ptr;

/*****
    The following code will initialize the File Block as needed.
*****/
    file_block.id = 0x4252;
    file_block.flags = F_NEAR+F_PAD; /* Set flags as appropriate.*/

    segread(&segregs); /* Obtain the register information. */
    file_block.table[0] = (WORD) table;
    file_block.table[1] = segregs.ds;
    file_block.parm_block[0] = (WORD) &parm_block;
    file_block.parm_block[1] = segregs.ds;

/*****
    The word at the PSP+2 is set by MS C to contain the next
    available paragraph number after this program. So if we
    subtract from this address the address of the PSP then we get
    the size of this program in paragraphs.
*****/

    ptr.half_ptr[0] = 2; /* Set the offset to two, */
    ptr.half_ptr[1] = _psp; /* and the segment to the PSP. */
    tsize = *(ptr.psp_ptr) - _psp;

    ptr.half_ptr[0] = 0; /* Set the offset to zero, */
    ptr.half_ptr[1] = _psp; /* and the segment to the PSP. */

/*****
    Establish the connection between C and the PSP.
*****/

```



```

*****/
ptr.psp_ptr[46] = (WORD far) &file_block; /* Set into the PSP
the offset and */
ptr.psp_ptr[47] = segregs.ds; /* segment address
of file_block */

xwait[0] = ptr.psp_ptr[5]; /* Store into XWAIT the offset */
xwait[1] = ptr.psp_ptr[6]; /* and segment address of DOS's
terminate routine. */

xbye[0] = xwait[0]; /* Copy the termination segment and */
xbye[1] = xwait[1]; /* offset address, from above, into
here. */

xwait[0] += 3; /* incr by 3 for normal call */
xbye[0] += 6; /* incr by 6 for termination */

/*****
Execute the function called from PC Scheme.
*****/

while (xli_wait()) {
    switch (parm_block.select) {
        case 0: parm_block.return_value =
            (double)output(
                (int)floor(parm_block.arg1 + .5));
            break;
        case 1: parm_block.return_value = inp(0x278);
            break;
        default: ;
    } /* end switch */

    parm_block.return_type = RT_DOUBLE;
} /* end while */

xli_bye();
} /* end main */

```

```

/*****
Convert to binary coded decimal format and output to port 0x278.
*****/

output(value)
int value;
{
    int high,low;
    low = value % 10;
    high = (value / 10) % 10;
    value = (high << 4) + low;
    outp(0x278,value);
}

```

APPENDIX D

NAPP Data Files

Appendix D contains the data files used by NAPP. The files included in this appendix are:

1. FIELD.MAP - This file contains the combined yield rate map and soil type map. This file is in comma separated variable (CSV) format and is read in by the PC Plus functions IMPORT and DOS-FILE-IN. This file is used by the recommendation system.
2. NRATE.MAP - This file contains the recommended nitrogen rate map produced by NAPP using the above field map and an intended crop of non-irrigated wheat with a yield goal of 60 bu/Acre. This file is created using the PC Plus functions EXPORT and DOS-FILE-OUT in the recommendation system. Then, this file is searched to determine the nitrogen rate to be applied at the applicator vehicle's present location. It is searched by the control system using PC Scheme's user-written function GETNRATE (See Appendix B).
3. NEQN.DAT - This file contains the crop dependent nitrogen rate recommendation equation coefficients. This file is searched by the recommendation system using the PC

Scheme's user-written function NEQDATA (See Appendix B).

4. SITE.DAT - This file contains the path taken by the applicator vehicle. This file is in CSV format and is read in by the PC Plus functions IMPORT and DOS-FILE-IN. This file is used to control the operation of NAPP's control system.

FIELD.MAP

4,WHEAT,51,RL
 0,0,55,SILT LOAM
 0,1,55,SILTY CLAY LOAM
 0,2,52,SILTY CLAY LOAM
 0,3,47,SILTY CLAY LOAM
 0,4,45,SILT LOAM
 0,5,47,SILT LOAM
 0,6,50,SILT LOAM
 1,0,55,SILT LOAM
 1,1,53,SILTY CLAY LOAM
 1,2,50,SILTY CLAY LOAM
 1,3,50,SILTY CLAY LOAM
 1,4,46,SILT LOAM
 1,5,45,SILT LOAM
 1,6,47,SILT LOAM
 2,0,55,SILT LOAM
 2,1,51,SILTY CLAY LOAM
 2,2,51,SILTY CLAY LOAM
 2,3,54,SILTY CLAY LOAM
 2,4,51,SILTY CLAY LOAM
 2,5,48,SILT LOAM
 2,6,46,SILT LOAM
 3,0,53,SILT LOAM
 3,1,50,SILTY CLAY LOAM
 3,2,52,SILTY CLAY LOAM
 3,3,57,SILTY CLAY LOAM
 3,4,55,SILTY CLAY LOAM
 3,5,50,SILT LOAM
 3,6,50,SILT LOAM
 4,0,48,SILT LOAM
 4,1,48,SILT LOAM
 4,2,51,SILTY CLAY LOAM
 4,3,55,SILTY CLAY LOAM
 4,4,58,SILTY CLAY LOAM
 4,5,54,SILTY CLAY LOAM
 4,6,53,SILT LOAM
 5,0,45,SILT LOAM
 5,1,45,SILT LOAM
 5,2,47,SILTY CLAY LOAM
 5,3,52,SILTY CLAY LOAM
 5,4,55,SILTY CLAY LOAM
 5,5,55,SILTY CLAY LOAM
 5,6,55,SILT LOAM

NRATE.MAP

0	0	86
0	1	86
0	2	81
0	3	72
0	4	69
0	5	72
0	6	77
1	0	86
1	1	83
1	2	77
1	3	77
1	4	70
1	5	69
1	6	72
2	0	86
2	1	79
2	2	79
2	3	84
2	4	79
2	5	74
2	6	70
3	0	83
3	1	77
3	2	81
3	3	90
3	4	86
3	5	77
3	6	77
4	0	74
4	1	74
4	2	79
4	3	86
4	4	91
4	5	84
4	6	83
5	0	69
5	1	69
5	2	72
5	3	81
5	4	86
5	5	86
5	6	86

NEQN.DAT

```
(CROP CROP TYPE NX1 NX2 EASTERN_YG CENTRAL_YG WESTERN_YG)
(CORN-D ROW 1.30 5 120 65 0)
(CORN-I ROW 1.35 5 163 163 163)
(WHEAT-D GRAIN 1.75 3 55 53 35)
(WHEAT-I GRAIN 1.75 3 75 75 75)
```

SITE.DAT

0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
1,6
1,5
1,4
1,3
1,2
1,1
1,0

APPENDIX E
KSU Soil Testing Laboratory recommendation
software's rounding procedure

The KSU Soil Testing Laboratory recommendation software rounds off its recommended nitrogen rate to the nearest ten's digit. The procedure to round off the rate is to add five to the nitrogen rate obtained by the recommendation equation, divide by ten, round to the nearest whole number, and then multiply by ten. This method causes a nitrogen rate that is greater than 10 and less than 20 to be rounded to 20. The nitrogen rate recommendation equation coefficients are adjusted to obtain the proper results from the equation with this rounding procedure in place. Therefore, in order to use the nitrogen rate recommendation equation and its coefficients this unusual rounding procedure must be accounted for. The NAPP system rounds the recommended nitrogen rate to the nearest whole number, requiring a different method of adjustment to account for this rounding procedure. The nitrogen rate is adjusted by adding 4.5 to the rate obtained from the nitrogen rate recommendation equation and truncating to a whole number. This procedure allows for approximately the same effect as the rounding procedure in the Soil Testing Laboratory's recommendation software.

AN INTELLIGENT CHEMICAL RECOMMENDATION
AND APPLICATOR CONTROL SYSTEM
FOR SITE-SPECIFIC CROP MANAGEMENT

by

MARTIN LEROYCE EIS

B.S., Kansas State University, 1986

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

ELECTRICAL AND COMPUTER ENGINEERING

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1989

Abstract

The objective of the research described is to create a general purpose system to aide in site-specific crop management using artificial intelligent techniques. This system combines spatial variability data into a map of the field, recommends the rate at which the desired chemical be applied, and controls the applicator vehicle applying the chemical.

The general purpose intelligent chemical recommendation and applicator control system is used in creating a system for recommending and controlling nitrogen being applied to the field. The recommendations are compared to present recommendations made at the Kansas State University Soil Testing Laboratory. Results suggest that the system developed has potential use in site-specific crop management.